The Tropospheric Wind Lidar Technology Experiment (TWiLiTE): An airborne direct detection Doppler lidar instrument development program

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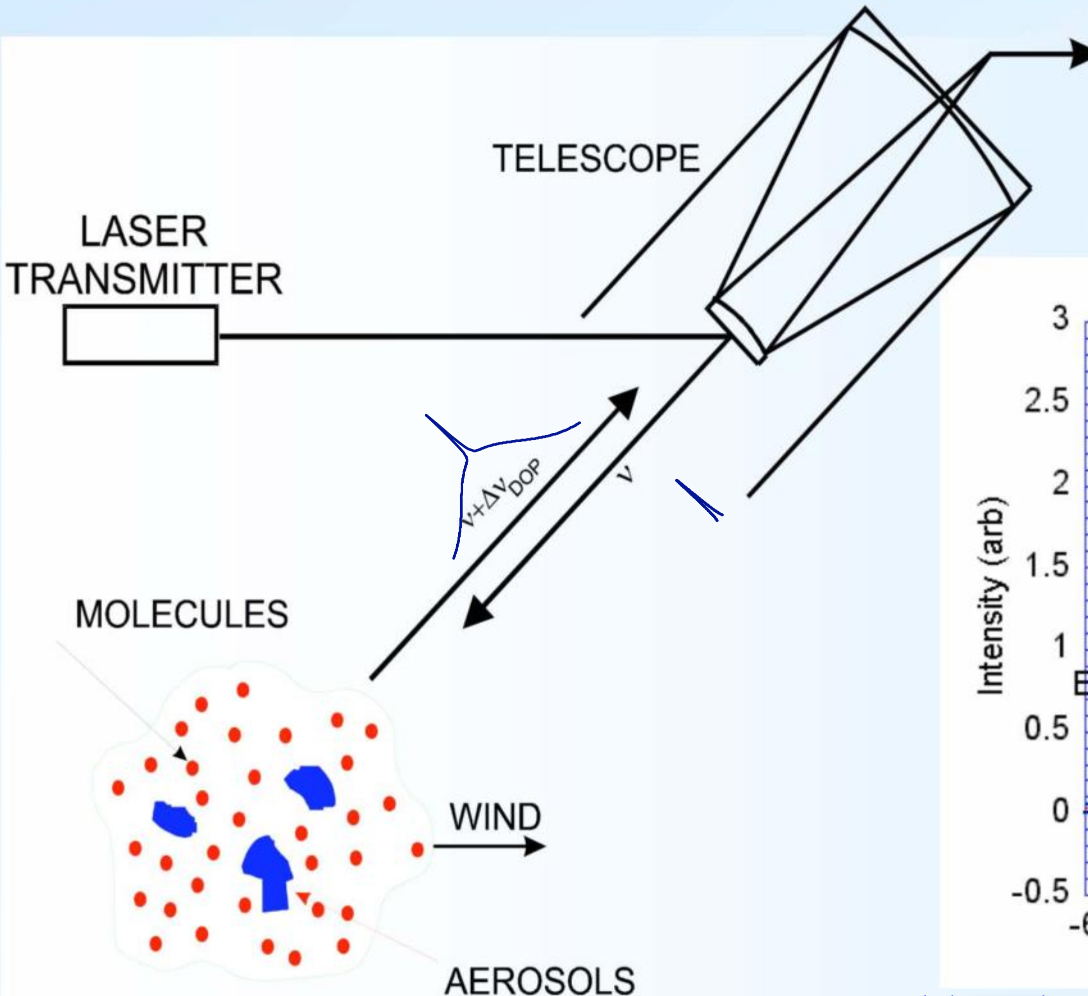
College Park, MD

Outline

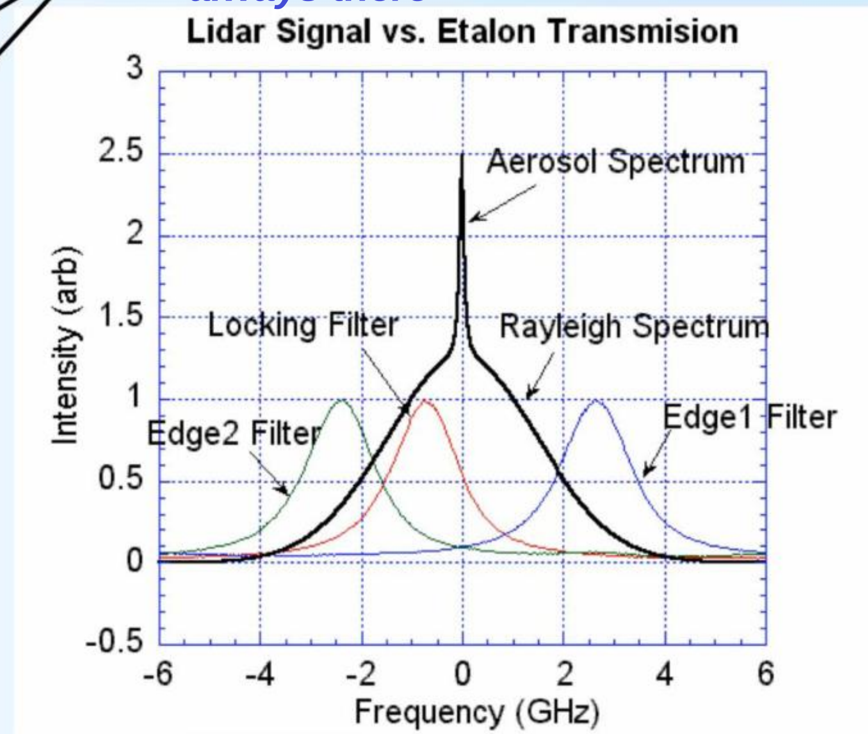
- Introduction and background
- TWiLiTE Overview
- Requirements and Performance Simulations
- WB57 Aircraft and Instrument Subsystems
- Summary

Doppler Lidar Measurement Concept



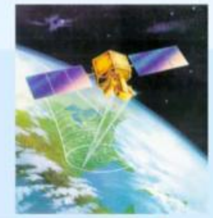
MOLECULAR DOPPLER RECEIVER

- Molecular return gives lower accuracy and resolution but ***signal is always there***



Double-edge filters sample wings of molecular spectrum to measure Doppler shift

Mission Applications



Global Tropospheric Wind Sounder

- *Improved NWP*
- *Hurricane and severe storm prediction*

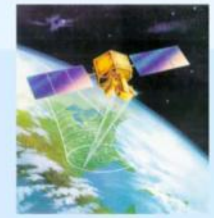
Airborne Doppler Lidar

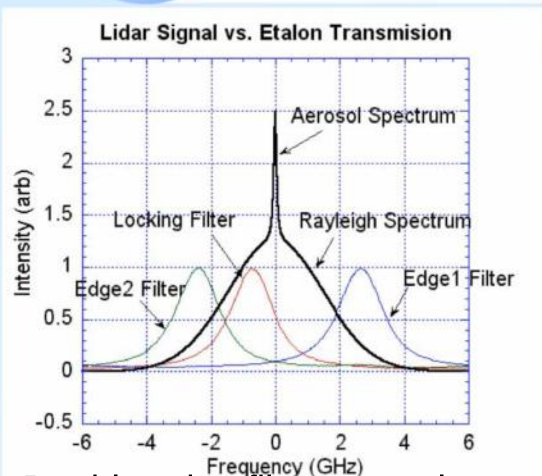
- *Mesoscale research*
- *Improved hurricane prediction*
- *Satellite cal/val*
- *Technology validation*

Exploration

- *Martian winds from orbit or surface*

Double Edge Doppler Lidar Heritage



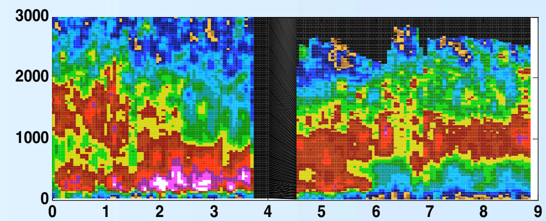


Double-edge filters sample wings of molecular spectrum to measure Doppler shift

GLOW mobile Doppler lidar

- In 1999 the first molecular “double edge” Doppler receiver was built as a proof of principle experiment.
- The molecular receiver was installed in the GLOW mobile Doppler lidar to demonstrate the functionality and scalability of the approach
- 5 years of ground based lidar wind measurements in a wide variety of conditions.

Receiver mounted in GLOW lidar for field tests and measurements



m/s

deg

Time series of wind speed and direction profiles from IHOP_2002

TWiLiTE Instrument Incubator Program (IIP)

- High altitude airborne molecular direct detection scanning Doppler lidar (DDDL)
- Serves as a system level demonstration of key DDDL technologies and subsystems
- Leverages technology investment from multiple SBIRs, ESTO, IPO and internal funding
- Consistent with the roadmap and planning activities for future space based direct detection and ‘hybrid’ Doppler lidar implementations

Proposed TWiLiTE Measurement Requirements

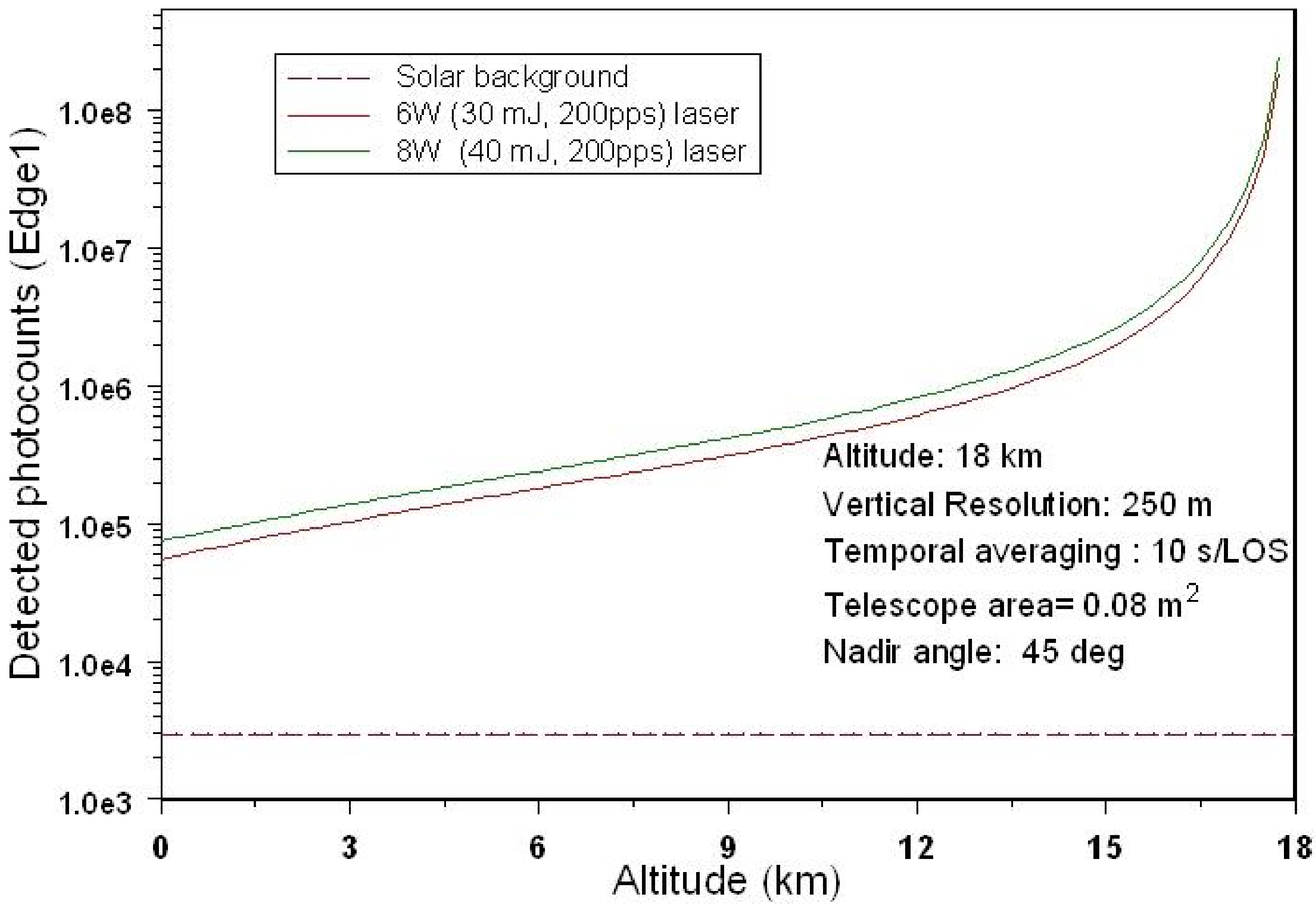
Parameter	***WB57***
Velocity accuracy (HLOS projected) (m/s)	2.0
Range of regard (km)	0-18
Vertical resolution (km)	0.25
Horizontal resolution (km) (scan pattern cycle)	25
Groundspeed (m/s)	200
Nadir angle (deg)	45
Scan pattern	Up to 16 pt step-stare
Horizontal integration per LOS (seconds)//ground track (km)	10//2

*** Assumes scanner average angular velocity of 12 deg/sec**

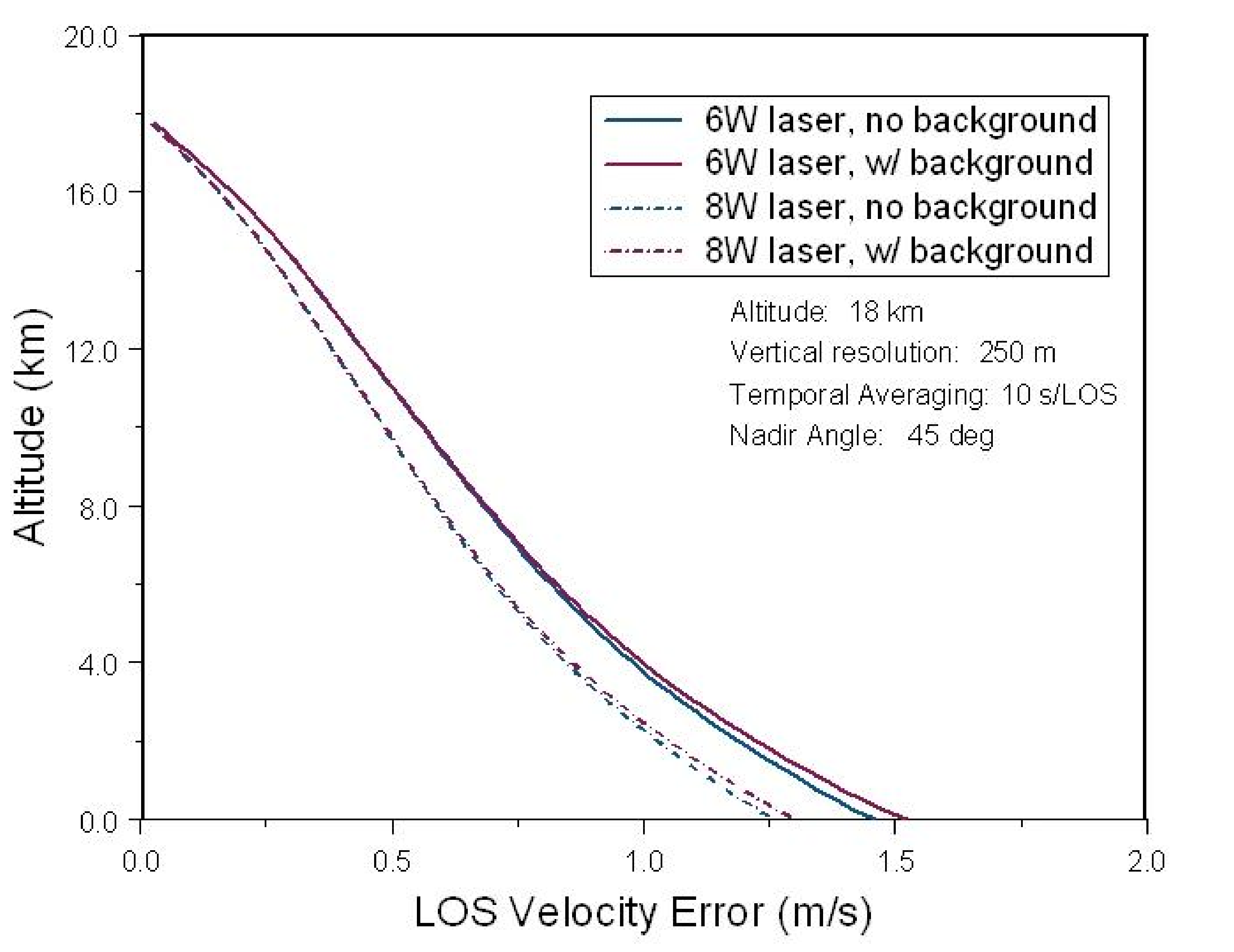
TWiLiTE Instrument Parameters

Wavelength	354.7 nm
Telescope/Scanner Area	0.08 m^2
Laser Linewidth (FWHH)	150 MHz
Laser Energy/Pulse (6 W)	30 mJ @ 200 pps
(8 W)	40 mJ @ 200 pps
Etalon FSR	16.65 GHz
Etalon FWHH	2.84 GHz
Edge Channel Separation	6.64 GHz
Locking Channel Separation	4.74 GHz
Interference filter BW (FWHH)	120 pm
PMT Quantum Efficiency	25%
Optical Efficiency (Edge w/o BS or etalon)	0.37
BS	0.41

Predicted Photocounts/range bin for Edge Channel 1

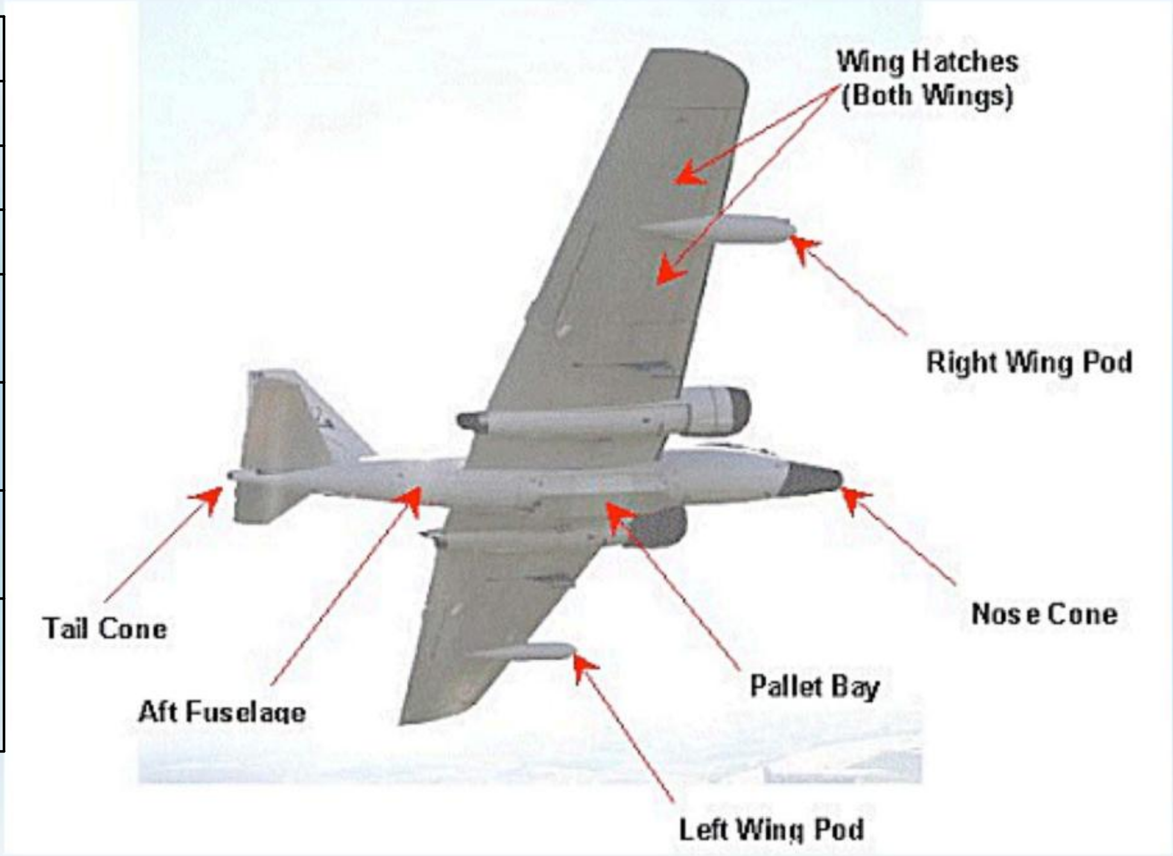


TWiLITE Shot Noise Limited Velocity Error



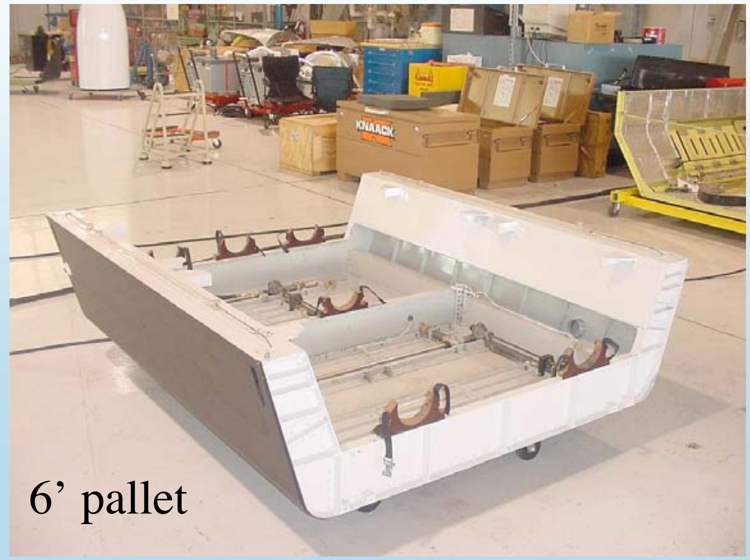
NASA Johnson WB57 Aircraft

Specification	WB57
Max. Altitude	18 km
Duration	6.5 hours
Cruise Speed	210 m/s @ 18 km
Payload mass	1814 kg (incl. pallets)
Payload Electrical Power	4 X 25 A , 3 phase, 400 Hz
Payload mounting	Modular pallet Nadir view
Window diameter; viewing orientation	45 cm; nadir view



WB57 Instrument Mounting

3’ pallet

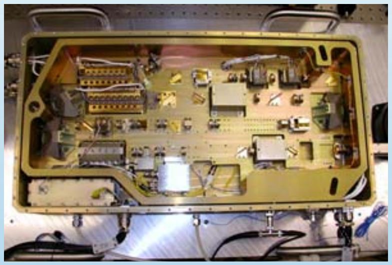


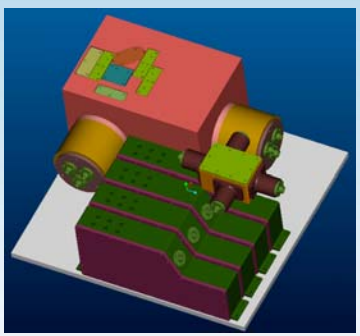
6’ pallet

Pallet integration

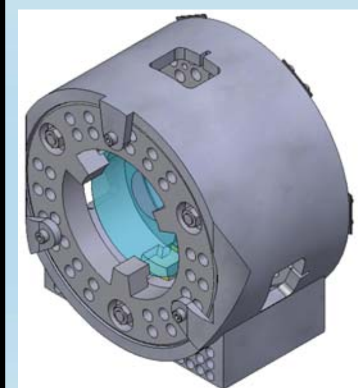
Looking forward from inside the payload bay

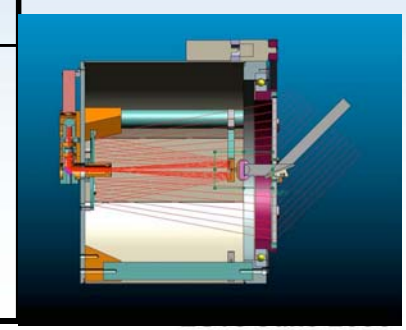
TWiLiTE Direct Detection Wind Lidar Key Technologies



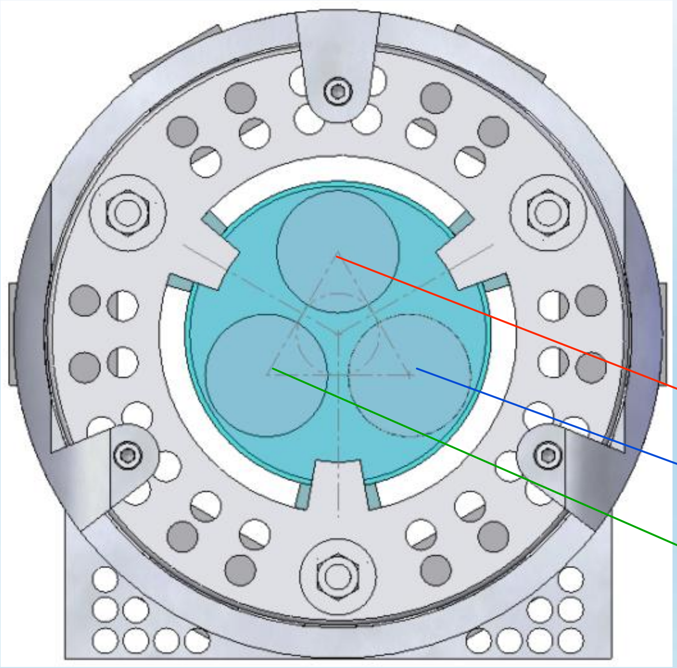


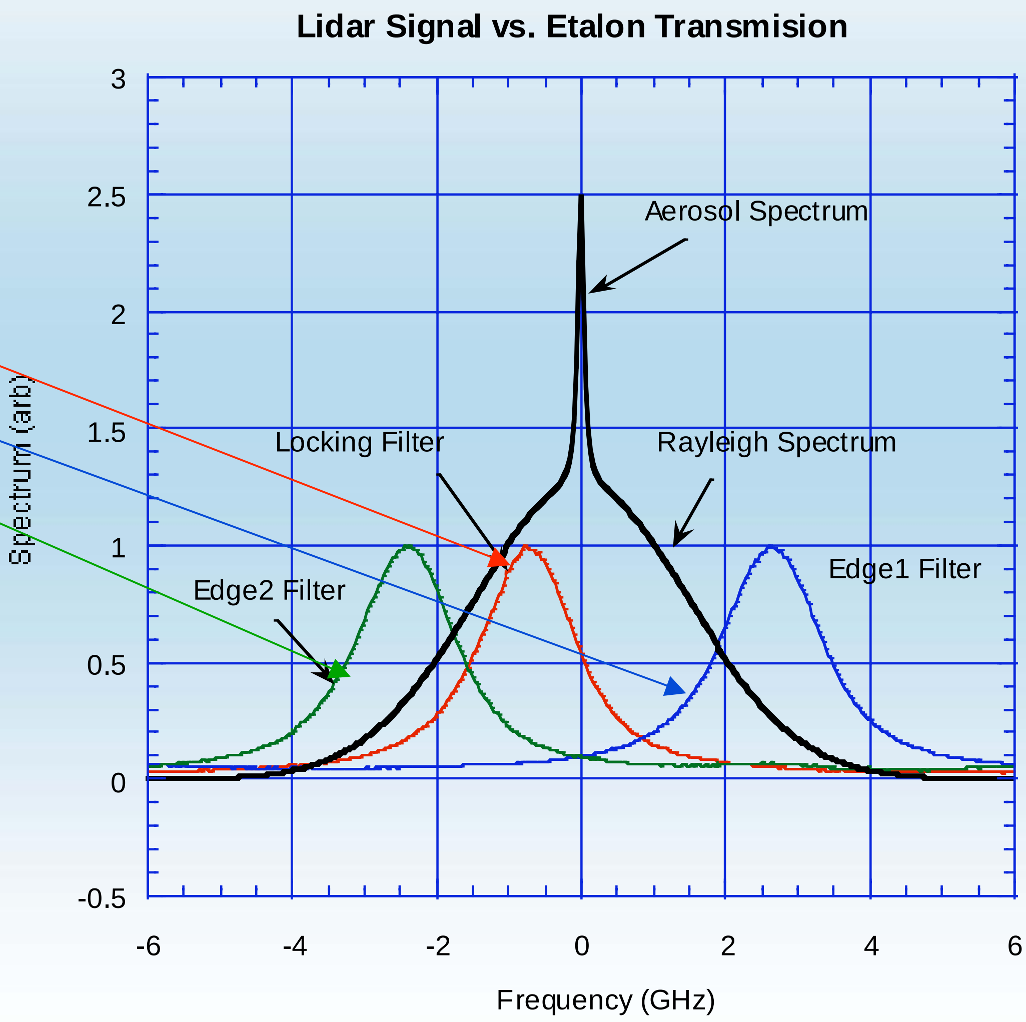
	Entrance TRL	Exit TRL
• High spectral resolution all solid state laser transmitter	4	5-6
• High spectral resolution optical filters	4	5-6
• Efficient 355 nm photon counting molecular Doppler receiver technologies	4	5-6
• Novel UV Holographic Optical Element telescopes and scanning optics	3	5-6





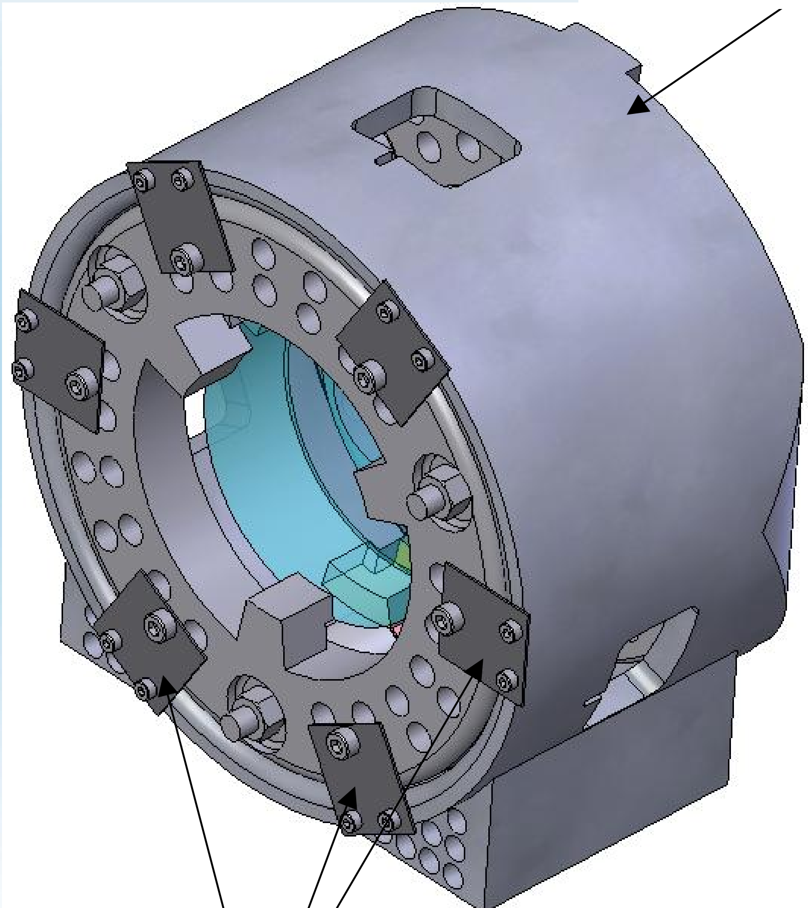
Double Edge Etalon Channels

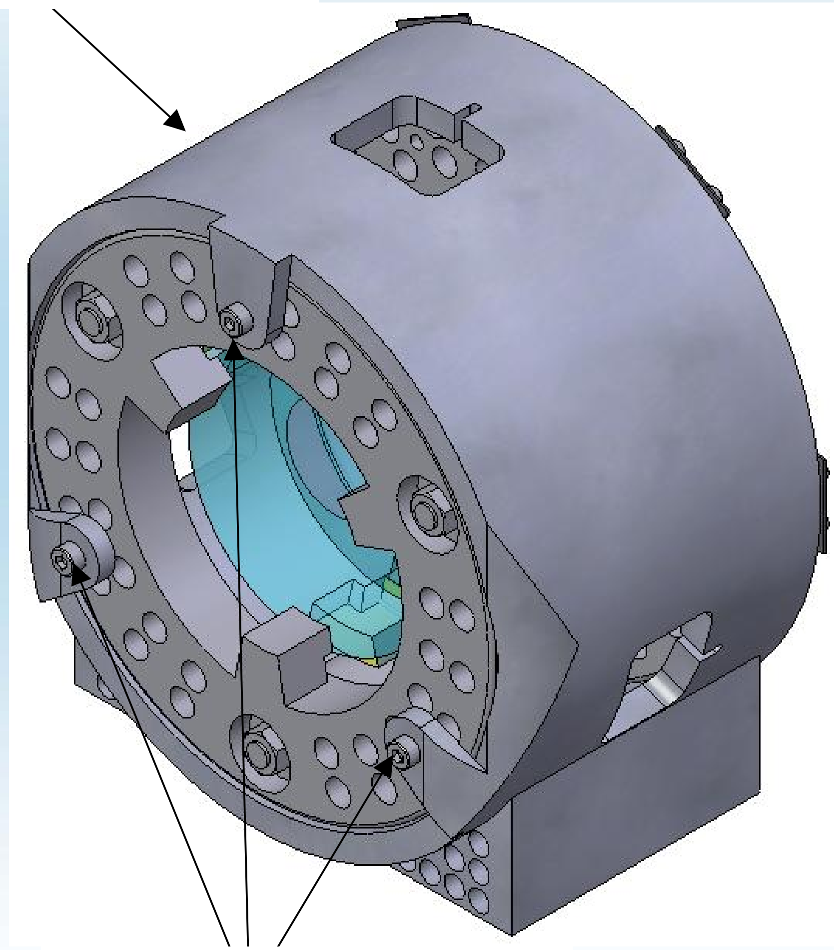




Michigan Aerospace TWiLiTE Etalon

Invar housing machined from solid piece ensures material homogeneity, rigidity and minimizes thermal deformation



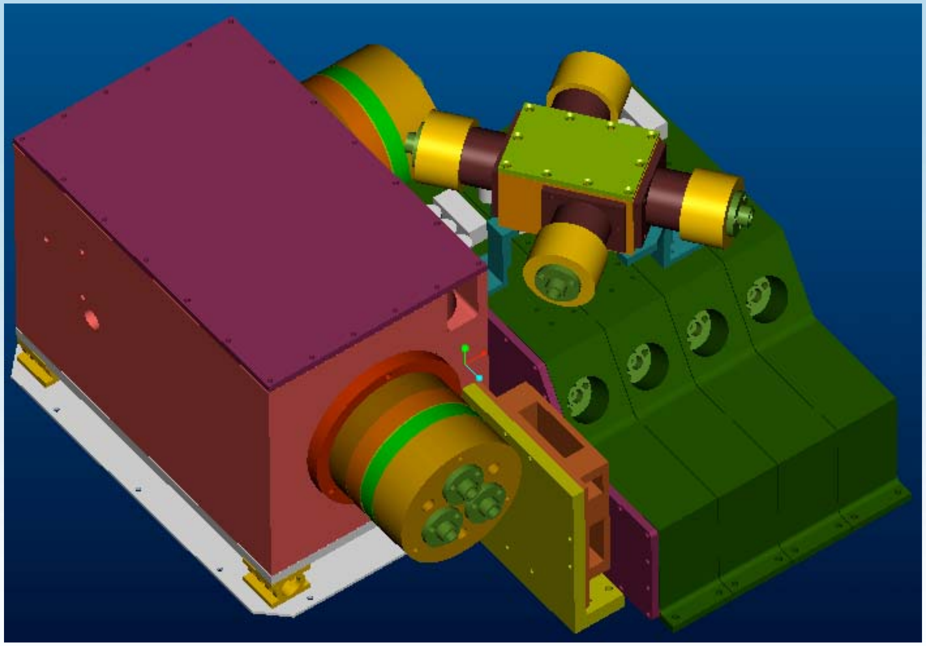


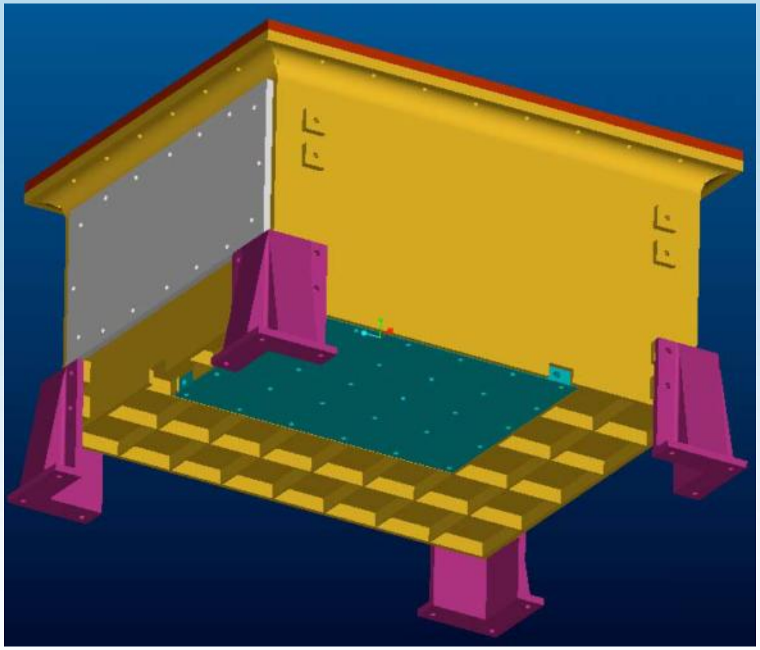
'Soft' diaphragm mounting on actuated ring allows for tuning with a minimal amount of stress imparted to the ring/plate assembly while holding the etalon rigidly centered on optical axis.

3 point rigid mount at input creates stress free reference plane and stable angle of incidence

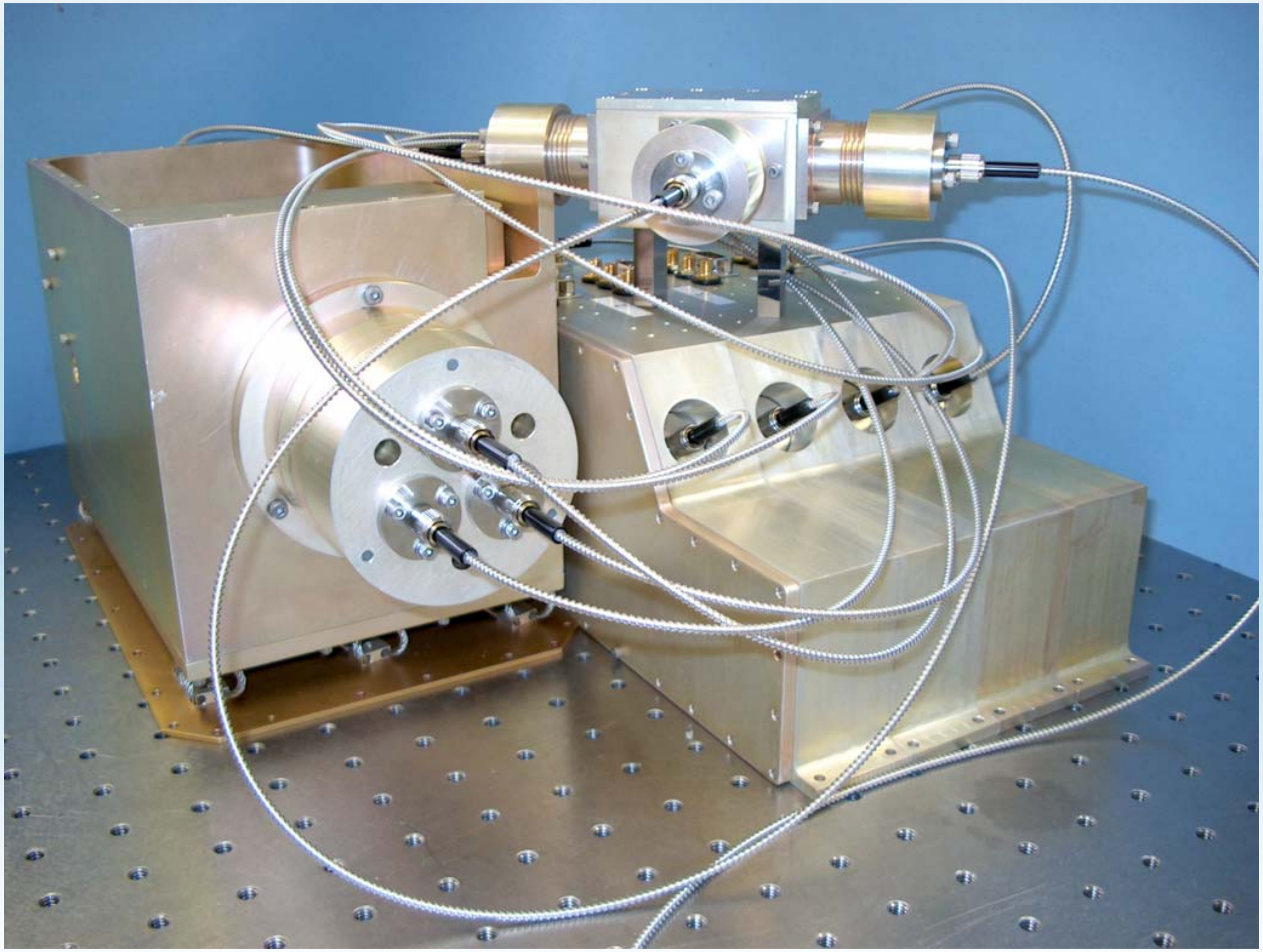
IRAD Receiver Design Summary

- Volume reduced by 90% versus current GLOW receiver
- Optical path lengths minimized to improve mechanical, thermal stability
- End-to-end throughput increased by 60%
- Signal dynamic range increased by 2 orders of magnitude



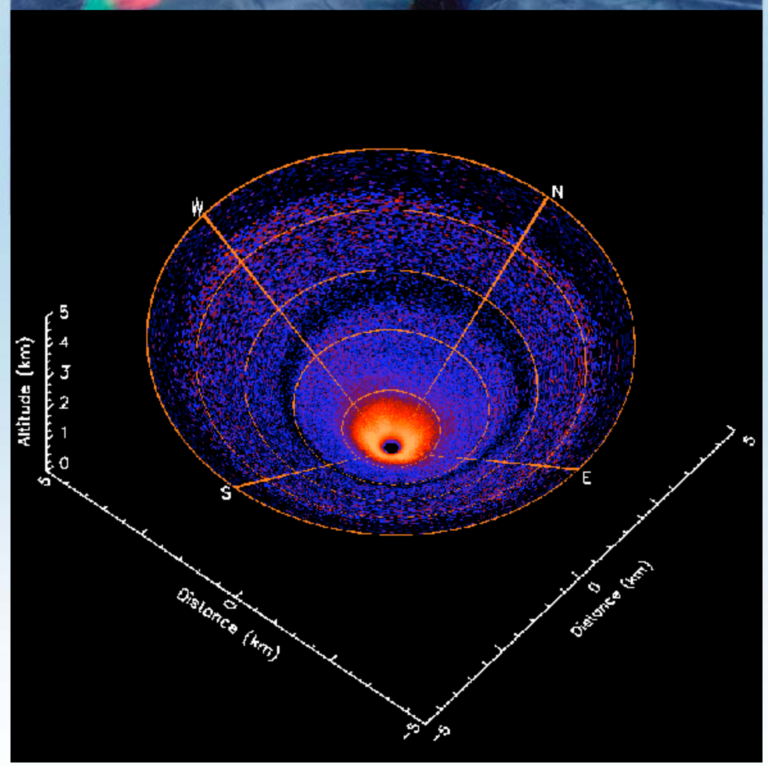


Assembled Receiver Box System



HOE/Scanner Heritage

- Significant NASA Investments since 1990
- PHASERS lidar (532 nm) 1994-present
- HARLIE airborne lidar (1064 nm) 1998-present – extensive field use
- UV HOEs (355 nm) 2000-present
- 2 NASA patents, 3 USU patents
- Contributors: Thomas Wilkerson (SDL/USU), Richard Rallison (Ralcon), David Guerra (St. Anselm)



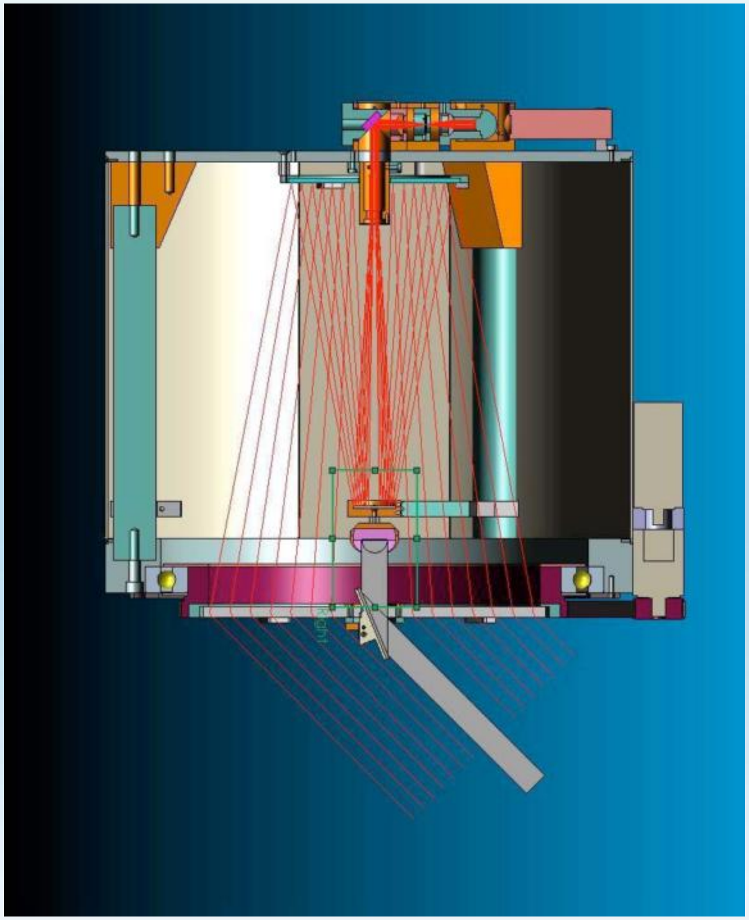
TWiLiTE Holographic Telescope

FUNCTIONS

- **Collect and focus laser backscatter**
- **Scan laser and FOV**
- **Provide pointing knowledge to CDH**

FEATURES

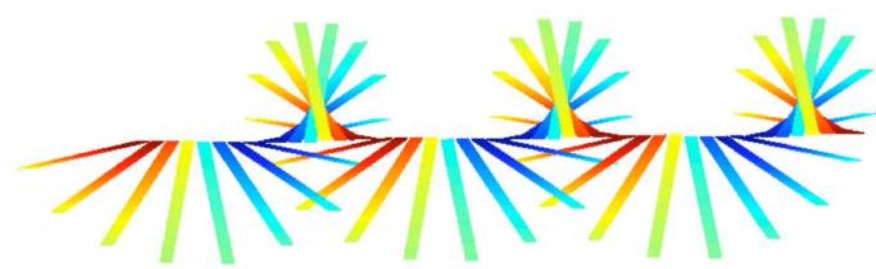
- **Primary Optic: Rotating 40-cm HOE, 1-m f.l.**
- **45-deg off-nadir FOV**
- **Compact, folded optical path**
- **Coaxial laser transmission**
- **Active laser bore-sight**

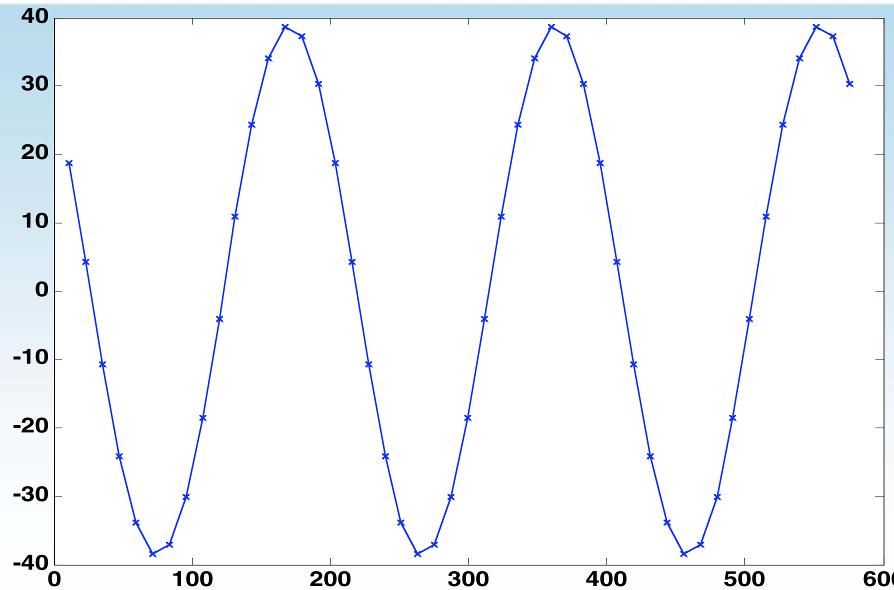


Conical step stare scan pattern

Scanning parameters:

- Constant dwell of 10s/LOS
- Scanner angular velocity of 12 deg/sec
- 192 sec to complete one cycle





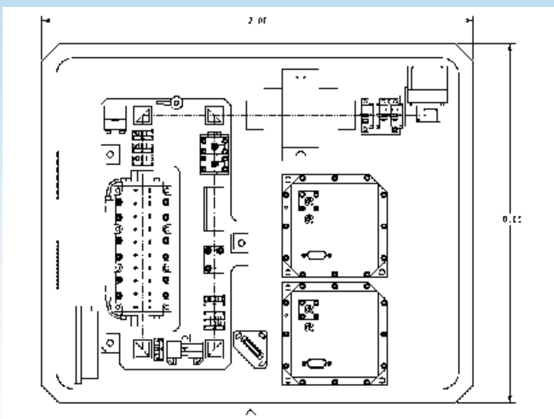
Radial HLOS wind speed measured in a single range bin for 3 cycles of the 16 point step stare scan pattern. Assumes constant velocity (maximum = 40 m/s)

TWiLiTE Laser Requirements

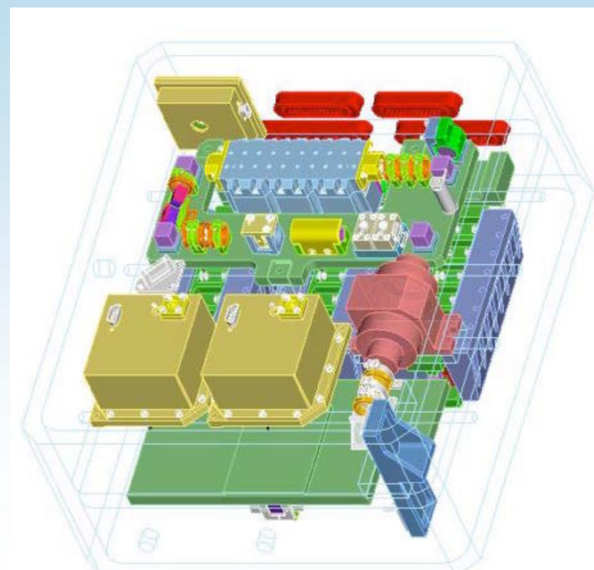
	Specification	Note
Laser Energy per Pulse	30 mJ < E < 40 mJ @ 355 nm	Dark count rate near ground is comparable to signal count rate for 0.5 mJ/pulse laser energy.
Laser Pulse Repetition Freq (Hz)	200 (250 objective)	
Pulse Width	> 15 ns @ 1064 nm	
Linewidth	< 120 MHz @ 355 nm	
Frequency Stability	< 5MHz RMS for 30 sec < 50 MHz RMS for 30 min	< 0.25 m/s wind error
Seeding Efficiency	> 99.9%	
Beam Quality	$M^2 < 3$ @ 355 nm	
Energy in the Bucket	86% energy in 3 x DL	
Pointing Stability	< 1/10 laser beam divergence	
Cooling	Conductive or liquid cooled	
Lifetime	1×10^9 Shots	

Laser Approach

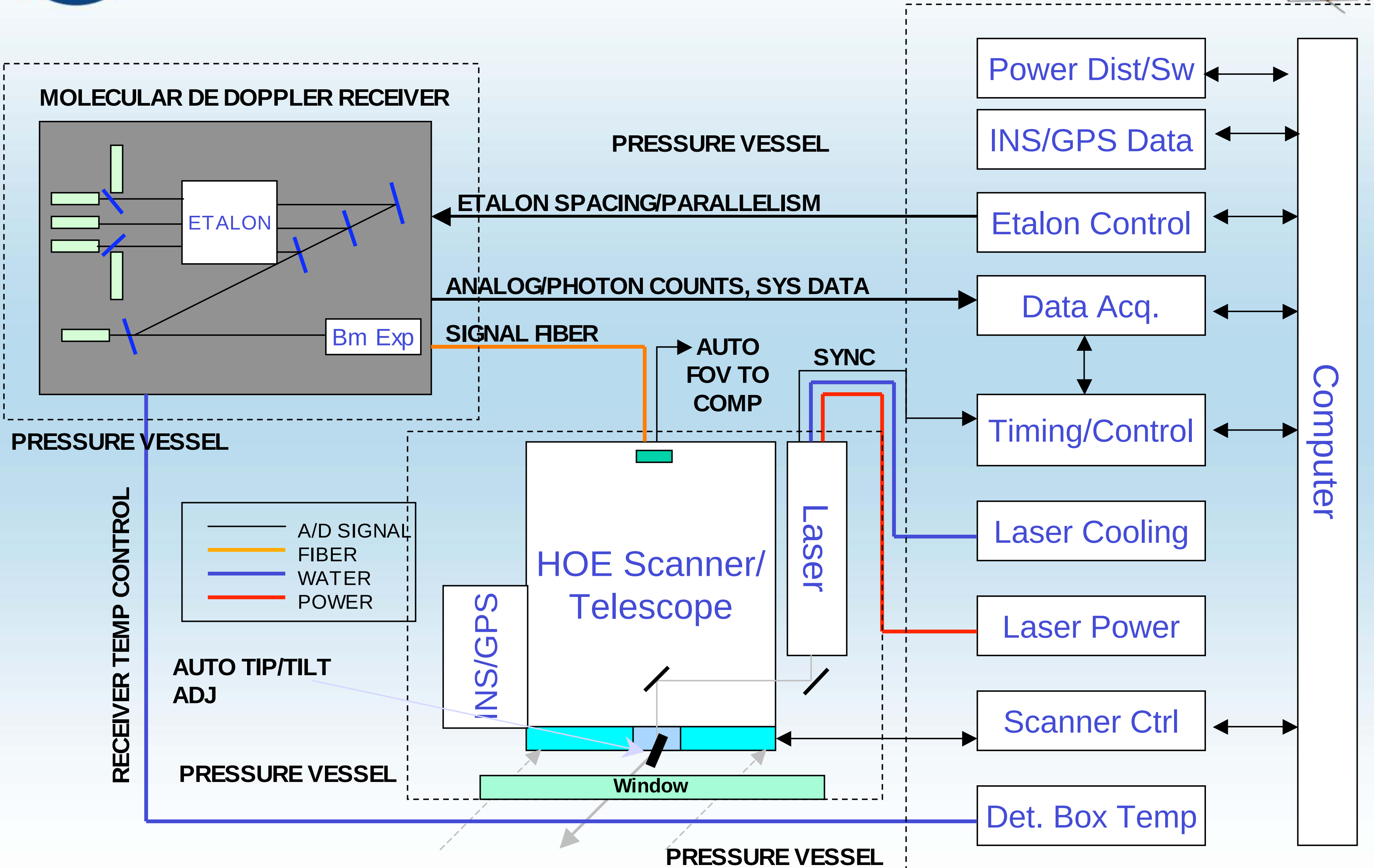
- Leverage significant SBIR and ESTO investments in single frequency, diode pumped laser designs
- The TWiLiTE laser will be a derivative of the SBIR High Brightness Laser developed by Fibertek. It will be scaled to higher rep rate (200 Hz vs 50 Hz) and higher average power (6 to 8W at 355 nm vs 2.5W) and repackaged in smaller footprint design suitable for aircraft operation.
- Coordinating transmitter development with LaRC HSRL/Ozone DIAL IIP program (C. Hostetler and J. Hair)



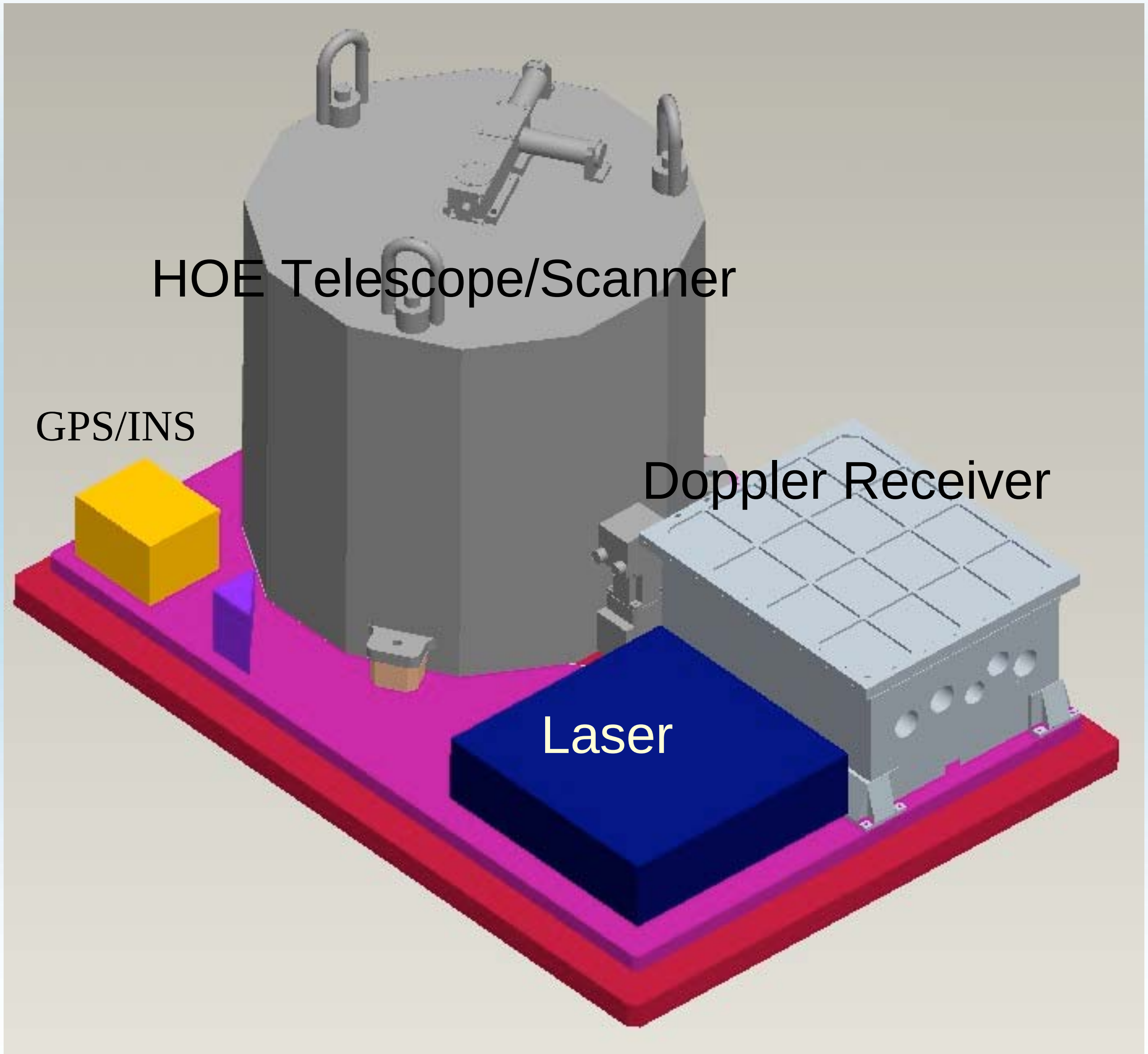
An ~ 31 cm x 25 cm x 14 cm canister will accommodate the required modules



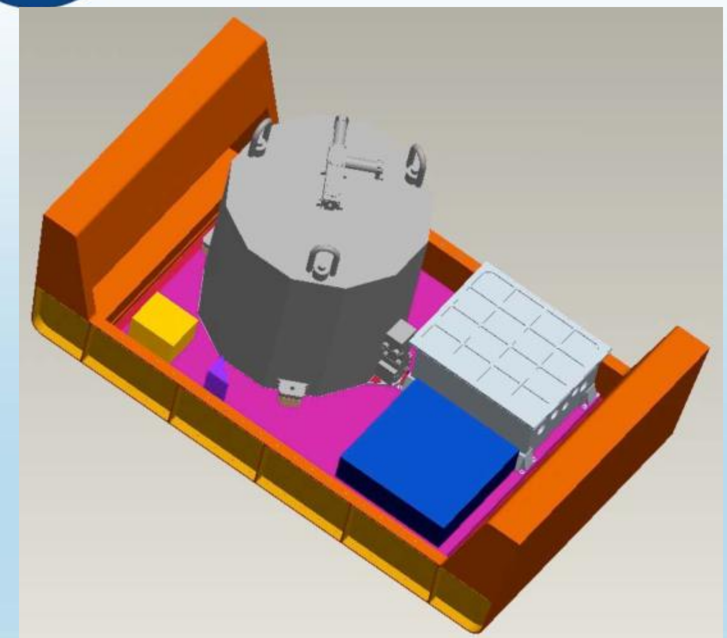
System Block Diagram

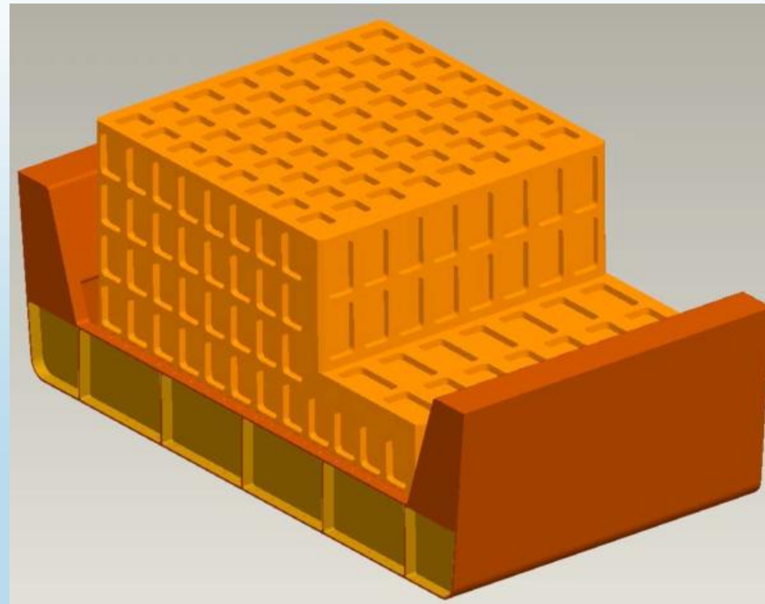


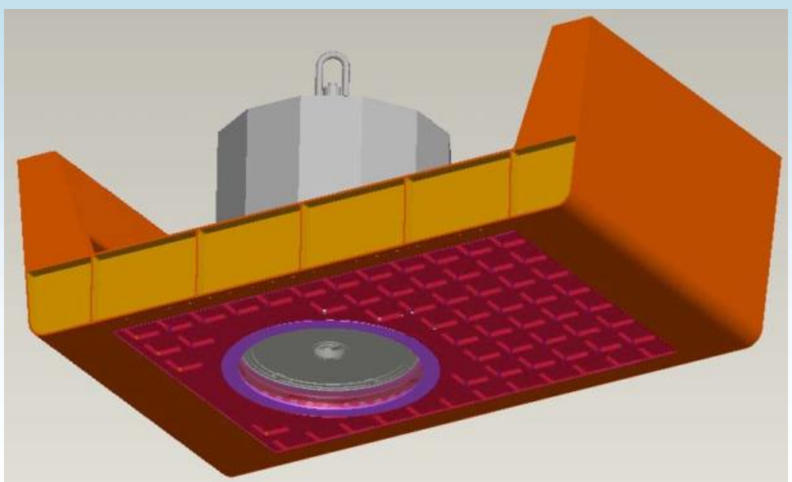
TWiLiTE Doppler lidar system layout



TWiLiTE Lidar Integrated on WB57 Pallet







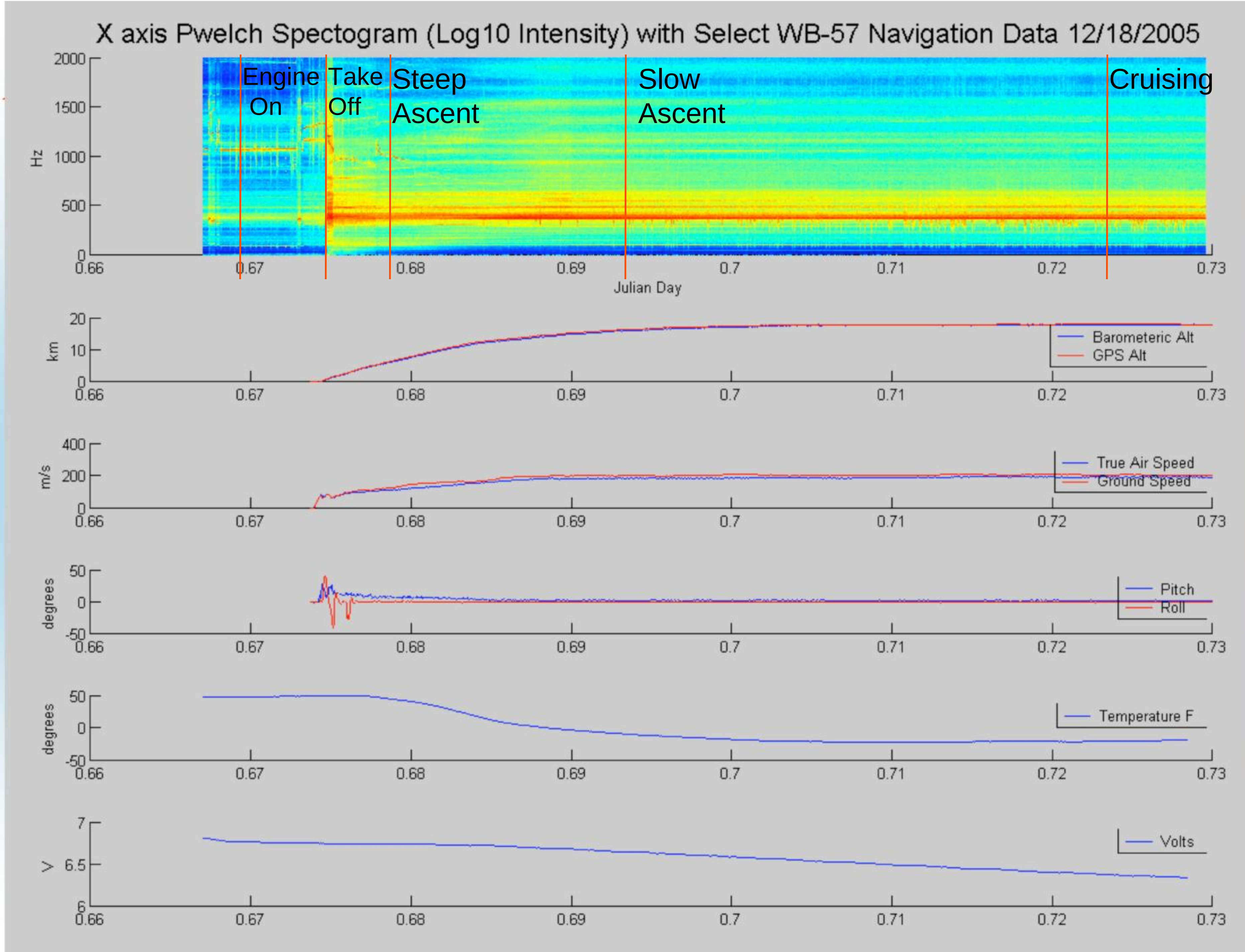
WB57 temperature and pressure environment may require enclosing some or all of the subsystems in a sealed enclosure

TWiLiTE Summary

- TWiLiTE is a three year R&D project to design and build an airborne scanning direct detection Doppler lidar
- The primary objective is to advance the TRL of key component technologies as a stepping stone to space.
- The TWiLiTE Doppler lidar will be serve as a testbed to validate critical technologies in a fully autonomous, integrated Doppler lidar as a stepping stone to space.
- The instrument will is designed to measure full profiles of winds from a high altitude aircraft and many of the design elements may be transitioned to UAV or other suborbital platforms for mesoscale and hurricane research.

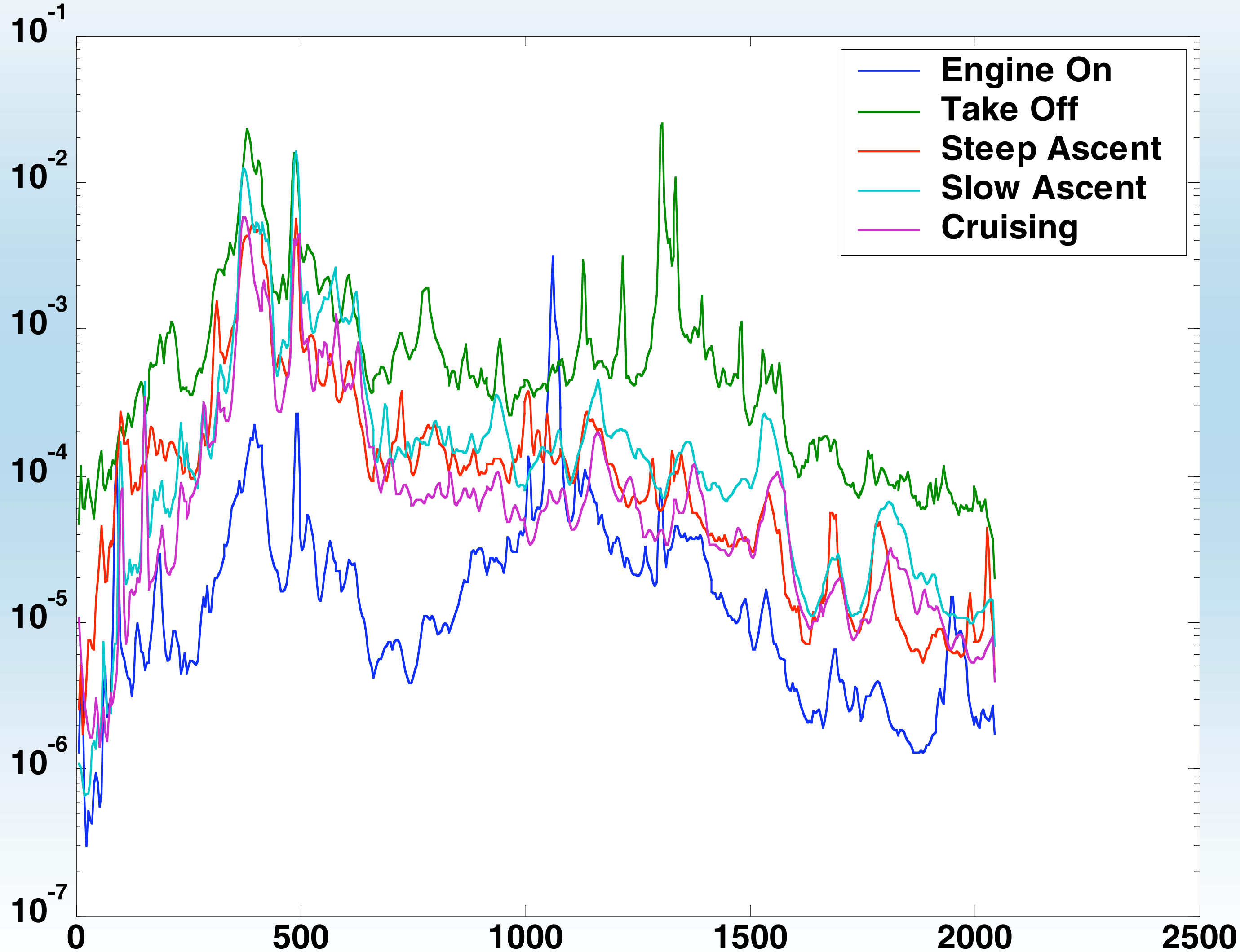
Acknowledgements: ESTO IIP Program; Goddard Space Flight Center IRAD program

Backups



X axis Pwelch Spectogram (Log10 Intensity) with Select WB-57 Navigation Data 12/18/2005
Engine On
Take Off
Steep Ascent
Slow Ascent
Cruising
Hz
Julian Day
km
Barometeric Alt
GPS Alt
m/s
True Air Speed
Ground Speed
degrees
Pitch
Roll
Temperature F
V
Volts

Three axis accelerometer data from WB57 at operating altitude - Flight 2, 12/18/2005



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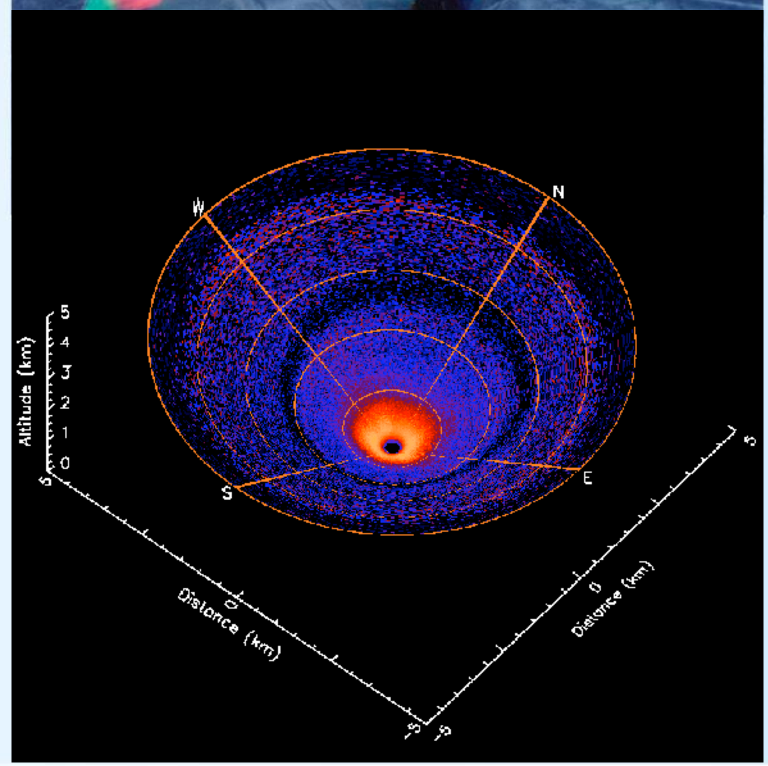
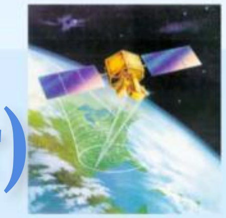


Top level error budget (6 W laser)



- Total LOS velocity accuracy 2.0 m/s
  - Photon shot noise 1.5 m/s
  - Doppler receiver spectral 0.35 m/s
  - Laser spectral 0.25 m/s
  - AC motion comp. 0.25 m/s
  - Margin 1.2 m/s

Total error $= 2.0$ m/s $= \mathrm{sqrt}(1.5^2 + 0.35^2 + 0.25^2 + 0.25^2 + 1.2^2)$

- High altitude airborne direct detection scanning Doppler lidar
- Serves as a system level demonstration and as a technology testbed
- Leverages technology investment from multiple SBIRs, ESTO, IPO and internal funding
- Consistent with the roadmap and planning activities for direct detection and ‘hybrid’ Doppler lidar implementations

Principal Investigator: Bruce Gentry, NASA/GSFC
Co-Investigators:
NASA/GSFC - Robert Atlas, Matthew McGill, Geary Schwemmer
NOAA ETL - R. Michael Hardesty, W. Alan Brewer
Space Dynamics Lab - Thomas Wilkerson

Partners: Michigan Aerospace Corporation - Scott Lindemann
Sigma Space Corporation - Joe Marzouk

Goddard Space Flight Center